

Analysis of System Loss Reduction through Recovery Preventive Maintenance (RPM) of kWh Meter Connections, PELCO I

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ABSTRACT

This study explores the impacts of Recovery Preventive Maintenance (RPM) on reducing system losses. With the primary objective of determining whether RPM can effectively improve meter performance associated with defective kilowatt-hour (kWh) meter connections at the Pampanga I Electric Cooperative Inc (PELCO I). The research essentially focused on before and after the implementation of the RPM, utilizing a mixed-method approach, using quantitative data on kilowatt-hour (kWh) system loss and cost savings with qualitative insights from field personnel. Based on findings, it was revealed that after implementing RPM, system loss decreases by 3,599 kWh, resulting in an annual savings of ₱34,118.52. The return on investment (ROI) is achievable within six years, with revenue return of ₱1.16 for every peso spent on RPM. The following recommendations were deducing, which includes expansion of fault classifications of meters, conducting similar studies across other branches, enriching literature review with recent and foreign studies, integrating more detailed cost-benefit and sensitivity analysis. Future research is then encouraged to use real-time data to validate RPM's long-term impact. The study affirms that RPM is an effective strategy for reducing system loss and enhancing electric distributions utility service reliability.

Keywords: Cost Savings; Kilowatt-Hour Meter; Non-Technical Energy Losses; Mixed-method Approach; System Loss Reduction; Pampanga I Electric Cooperative; Recovery Preventive Maintenance; Reliability; Quantitative Data; Qualitative Insights.

1. Introduction

Electric distribution utilities face constant challenges in ensuring the efficient delivery of electricity from source to consumer. To improve or maintain a quality service, utilities must provide the power quality in their distribution system while operating in a safe, efficient manner with a high degree of reliability as cited in Philippine Distribution Code (PDC), Section 3.1.1, Article a and b [1]. Each distribution utility has the responsibility to identify and correct problems in power quality, system loss, and reliability in its distribution lines. System reliability and efficiency are vital in today's operations for all electric utilities because they can be ranked and generate income for growth through revenue generation according to PDC, Section 6.2.1, Article c [1].

1.1. Study Objectives

The objectives outlined below were pursued:

1. Determine the system loss and percent system loss of kWh meters after using PELCO I's existing recovery preventive maintenance (RPM) for defective meters.
2. Determine the system loss and percent system loss that the defective kWh meters contribute in PELCO I before using recovery preventive maintenance by using Assumption-Based Computation.
3. Determine the total system loss reduced of kWh meters in terms of the system loss before and after using Recovery Preventive Maintenance (RPM).
4. Determine the electric energy (kWhr) saved after using recovery preventive maintenance (RPM) in terms of the system loss before and after recovery preventive maintenance (RPM).

5. Determine the Return of Investment (ROI) and the Cost Benefit Ratio after using recovery preventive maintenance (RPM), Case I.

2. System Losses in Distribution Utilities

One of the primary issues encountered by electric cooperatives that contributes to the system's reliability and performance efficiency, such as the Pampanga I Electric Cooperative Inc (PELCO I), is system loss. Based on Philippine Distribution Code (PDC) of 2017, Article 3.4.1 [1]. System loss in the electrical distribution system is defined as the unaccounted kilowatt-hour or the difference between the energy purchased or generated and the energy sold, which not only affects the operational performance but also impacts their service reliability and financial stability as outlined in System Loss Reduction Manual DX343 of National Electrification Administration [NEA] Bulletin [2].

System losses are classified in the Philippine Distribution Code, specifically PDC, Article 3.4.1 [1] into three categories: technical losses, non-technical losses, and administrative losses. Administrative losses refer to the energy used in the operation of the Distribution System (e.g., substation service) and any unbilled energy that is used for community-related activities, while non-technical losses is not related to the physical characteristics and functions of the electrical system, and is caused primarily by human error, whether intentional or not. Non-technical loss also includes the energy lost due to pilferage, tampering of meters, and incorrect meter reading. Technical losses, on the other hand, originate from electrical equipment such as conductors, meters, capacitors, and transformers. These include copper losses, core losses in transformers, and losses due to technical metering errors, and are inherent in the physical delivery of electric energy. It includes conductor loss, transformer core loss, and technical error in meters which was stated on PDC, Article 1.5 [1].

2.1. Standards, Loss Reduction Targets, and Components

Adjustments of the existing system are taken into consideration to comply with R.A. 9136, better known as the Electric Power Industry Reform Act (EPIRA) of 2001[3]. This law mandates the deregulation of the electric power industry, that there must be a competitive environment, improvement of the systems, minimizing line losses, and voltage profile enhancement. Having a definite policy, the objectives of EPIRA 2001 are to ensure the quality, reliability, security, and affordability in the supply of electric power; to protect the public interest as it is affected by the rates and services of electric utilities and other providers of electric power; to ensure a transparent and reasonable price of electric power services in a regime of free and fair competition to achieve greater operational and economic efficiency; and to ensure a guaranteed full recovery of all allowable generation costs as well as other costs associated with the system loss caps in an efficient and timely manner.

According to the NEA System Loss Reduction Manual (DX3430) [2] and the Philippine Distribution Code of 2017 [1], each electric distributor, including electric cooperatives such as PELCO 1, must reduce system losses to 12% or less in their distribution system. This 12% system loss is divided into six categories: substation losses (1%), primary lines (3%), transformer losses (3%), secondary lines (3%), service drops (1%), and kilowatt-hour meters (1%). Among these, primary lines, secondary lines, and transformer losses constitute the highest percentage because these

components are extensively used in the electrical distribution system, as well as for distribution transformers with the highest energy loss. In contrast, in a typical rural distribution system, components such as primary lines, secondary lines, service conductors, capacitors, and substation power transformers contribute lower losses. Kilowatt-hour meters, however, remain significant contributors to energy losses.

2.2. Role of kWh Meters and Sanitation Practices in System Losses

The primary contributors to non-technical losses are often driven by the poor sanitation and maintenance of kWh meter connections. Issues such as loose wiring, corroded connections, and outdated or faulty meters that lead to inaccurate electrical energy measurements, unbilled consumption, and increased chances or risk for tampering. These inefficiencies not only contribute to higher non-technical losses but also compromise customer trust and diminish service reliability as emphasized [4].

Enhanced sanitation of kWh meter connections has been identified as a crucial strategy to reduce system losses. Studies emphasize the importance of regular inspection, upgrading of old metering systems, and enforcement of anti-tampering measures. For instance, a study in 2022 by [4] highlighted that improving metering accuracy and addressing maintenance gaps in distribution systems can lead to significant reductions in non-technical losses.

2.3. Reducing Losses through Preventive Actions and Smart Metering

This study focuses on the Mexico Sta. Ana Branch of PELCO I, with 2.11% for the overall system loss of PELCO I, aiming to evaluate the impact of improved kWh meter sanitation on reducing system losses. The research will examine common issues in meter connections and implement targeted interventions to improve operational efficiency and reduce energy loss. The Pampanga I Electric Cooperative, Inc. (PELCO I) is committed to reducing system losses not only for regular mandates but also for operational sustainability. This commitment aligns with industry standards, helps avoid financial penalties, and ensures long-term viability as aligned to Philippine Distribution Code of 2017 [1]. As an electric cooperative that serves as an electric power distribution utility that distributes sufficient and stable power to the towns of Arayat, Candaba, Magalang, and San Luis, as well as Mexico and Sta. Ana in Pampanga. The cooperative operates seven substations located in Sto. Domingo (Mexico), Lagundi, San Nicolas (Magalang), San Isidro (Magalang), Sta. Monica (San Luis), Pandacaqui, and Plazang Luma (Arayat). PELCO I operate seven substations, each with multiple feeders, ensuring efficient power distribution across its service areas. The entire feeders are monitored for their reliability and efficiency. Even though the overall system loss of PELCO I is in a single-digit value of 5.18 % as of December 2024, the utility always aims to lower its percentage system losses and improve the distribution system to supply reliable and efficient electricity for its consumers. As stated, the total system loss of the utility is in single digits, but the field engineers of the utility (Technical Services Department and area engineers) continuously monitor and evaluate system losses in each feeder, focusing on operational improvement.

Preventive maintenance of kWh meters is essential to minimize system losses and measure energy accurately. Preventive Maintenance such as regular visual inspection, cleaning, calibration as needed, and securing meter connections by addressing any loose connections so that the equipment will not be tampered. According to Indriani et al. (2020) [5], If this maintenance work is inadequately performed, it may result in issues and damages, including

trips, corrosion, overheating, electrical short circuits, and potential building fires. Additionally, secure installations, like sealed enclosures, prevent access to meters by unauthorized people and environmental factors.

Successful programs to reduce losses through better kilowatt-hour (kWh) meter management have been undertaken in several cooperatives and states, demonstrating new practices and technologies. A prominent method is the use of smart metering systems, which have been demonstrated to greatly improve energy management and loss reduction. Smart meters give utilities real-time information on energy usage, enabling them to detect discrepancies and inefficiencies in a timely manner. For example, the deployment of smart meters has been associated with higher consumer sensitivity and participation with respect to the use of energy, resulting in more effective usage patterns and lowered operational losses to utilities as supported by Amaral et al. (2014) [6]. In addition, Cherchi et al. 2014) [7] mentioned that the installation of smart meters makes hinges easier because it provides automated meter reading, reducing human error as well as associated costs of manual readings.

The financial benefits of reducing losses systematically can be demonstrated through case studies that reflect considerable annual savings. For instance, a case study by Hernández-Escobedo et al. (2020) [8] on the implementation of rooftop solar photovoltaic (PV) systems connected to the grid led to energy savings of around 90,298 kWh annually. Furthermore, Jorge et al., (2021) [9] mentioned operational improvements that aim for energy recovery and optimization not only lead to less use of kWh but also help in diminishing carbon emissions and saving money by steering clear of excessive energy acquisition.

3. Methods

The current research adopts a mixed descriptive research design approach to determine the effect of recovery preventive maintenance of kWh meter connections on minimizing system losses in the Mexico Sta. Ana branch of PELCO I of Pampanga.

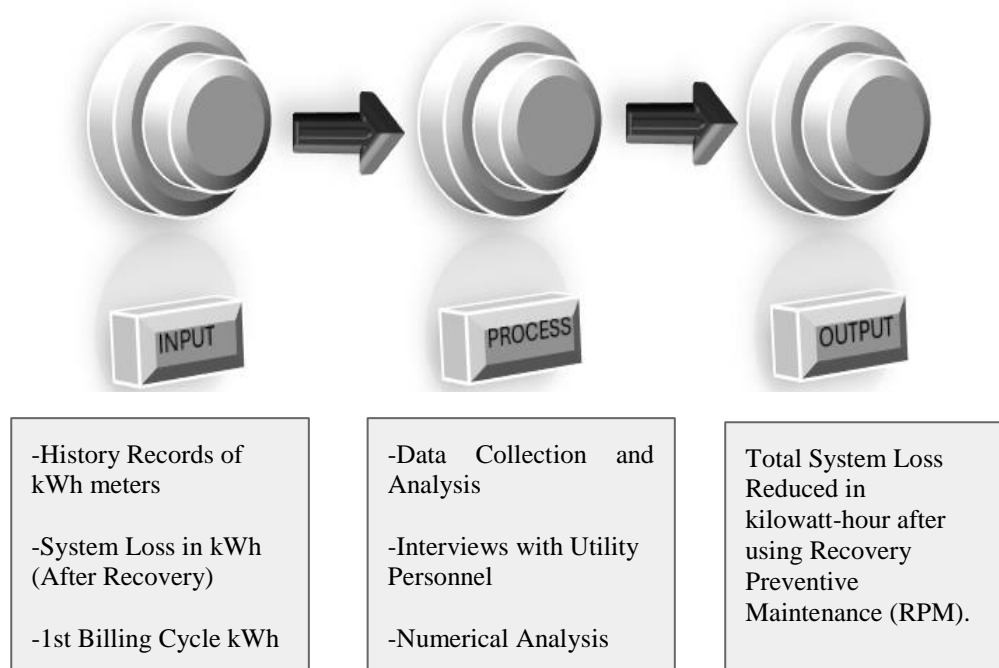


Figure 1. Conceptual Framework

Figure 1 shows a representation of the Input-Process-Output (IPO) conceptual framework guiding this research on minimizing system losses in kWh meter connections within the Mexico Sta. Ana branch of PELCO I. The input stage discusses the following available data of records of defective kWh meters in PELCO I for the computation of system loss kWh, system loss %, loss reduced kWh, energy saved and annual savings. The process phase; the researchers used a quantitative approach of gathering numerical data from system loss reports, kWh meter performance, and energy recovery metrics, with the Recovery Preventive Maintenance (RPM) approach interrogated both before and after implementation. To complement this, interviews were conducted with six officers involved in meter installation, maintenance, and monitoring. Thematic analysis and loss computation formulas were employed to support identification of patterns with faulting, affirm findings, and measure RPM strategies' operational impact. The research finding seeks to serve as a catalyst for main advancements; first, the reduction of system losses through better meter readings and reduction of unaccounted loss which have benefited operational efficiency for PELCO I Mexico Sta. Ana Branch, and second, the aim to make kWh meters better performers in achieving savings in kWh in terms of actual and recorded consumption of kWh meters to establish a sustainable and efficient power distribution system. By directly tackling these root problems, the research aims to create solutions that would foster long-term reliability and accuracy concerning kWh meter connections.

3.1. Research Locale

The study focuses on the Mexico Sta. Ana branch of Pampanga I Electric Cooperative Inc. (PELCO I), specifically targeting kWh meter connections that contribute to system losses.

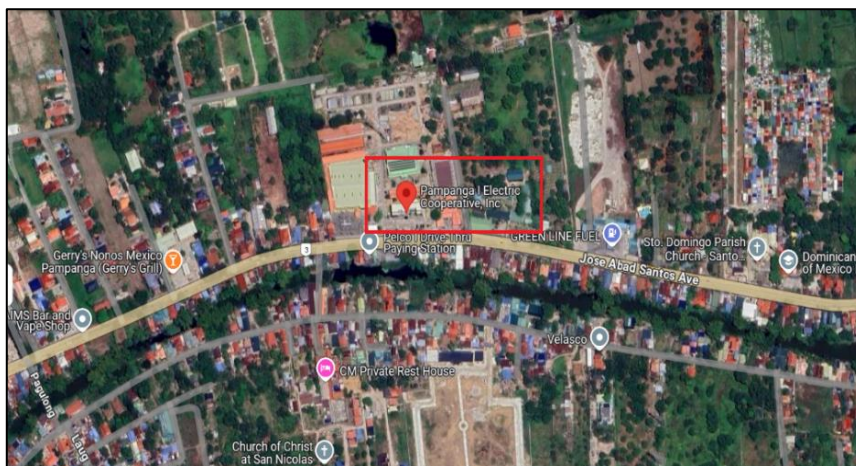


Figure 2. Mexico Sta. Ana Area Office Branch of Pampanga I Electric Cooperative Inc. (PELCO I)

Figure 2 shows the research locale of the study. This is a crucial location for investigation because PELCO I serve a wide range of customers in this area, including residential, commercial, and agricultural clients. It acts as a guide to selecting this branch, since there are recurrent issues with system losses, particularly those related to inefficient kWh meter connections, according to historical reports in the area of Mexico and Sta. Ana area.

3.2. Equations

Quantitative analysis deals with number-based data coming from PELCO I's historical records and updated operational records. The kWh meter readings, the recorded energy losses, the number of meters replaced, and the

energy savings resulting from Recovery Preventive Maintenance (RPM) are included. These data are analysed to determine the direct consequence of maintenance interventions on system performance.

The energy conservation, revenue recovery, and overall improvements in the system efficiency are calculated using standard engineering and regulatory formulas. These formulas are based on the computation guidelines as quoted from the Energy Regulatory Commission (ERC) and the National Electrification Administration (NEA) of the Philippines [10]-[11]:

$$\text{System Loss (\%)} = (\text{System Loss} / \text{Energy Input}) \times 100 \quad \dots(1)$$

$$\text{System Loss}_{\text{before RPM}} = \frac{\text{System Loss}_{\text{after RPM}}}{1 - \text{Reduction Rate}} \quad \dots(2)$$

$$\text{System Loss Reduced (kWh)} = \text{System Loss}_{\text{before RPM}} - \text{System Loss}_{\text{after RPM}} \quad \dots(3)$$

$$\text{Annual Savings (PHP)} = \text{Annual Energy Saved (kWh)} \times \text{Electricity Rate} \quad \dots(4)$$

$$\text{Return of Investment (ROI)} = \frac{\text{Initial Investment}}{\text{Annual Savings}} \quad \dots(5)$$

$$\text{Benefit-Cost Ratio (BCR)} = (\text{Total Benefits} / \text{Total Cost}) \quad \dots(6)$$

$$\text{Total Benefits} = \text{Annual Savings} \times \text{Period} \quad \dots(7)$$

Data will be tabulated, trends examined, and presented through graphs and tables using Microsoft Excel. The system performance both prior to and subsequent to the RPM intervention can be visually compared easily using this method. Trends in reduced losses and recovery of energy will be emphasized for evidence-based determination.

4. Results and Discussion

4.1. Quantitative Interpretation

The findings of this study were based on PELCO 1's available data record regarding the system loss in terms of before and after using Recovery Preventive Maintenance (RPM). Case I represents the data regarding kwh meters after using recovery preventive maintenance. While Case II represents the assumption-based analysis of the data regarding kwh meters before using recovery preventive maintenance. The time interval of averaging the system loss of defective meters in PELCO I is 12 months. Table 1 presents the summary of the total defective kwh meters. It also presents a breakdown of issues found in a sample of 118 electric meters inspected under recovery preventive maintenance. Table 2 shows the monthly summary of electricity sales in kilowatt-hours (kWh) for the year 2024. Table 3 presents the total kilowatt-hours (kWh) electricity rates and the average kilowatt-hour electricity rate for the year 2024.

Table 1. Summary of the Total Defective kWh Meters

Reason	Total Number of Meters	Total Percentage %
Change Meters	5	4.24
Stop Meters	77	65.25
Low Consumption	27	22.88
Reverse Meters	2	1.69

Defective Display	2	1.69
Low Voltage	1	0.85
Neutral Problem	1	0.85
Defective/Occupant	2	1.69
Melted	1	0.85
Total	118	99.153

Table 2. Monthly Summary of Electricity Sales in Kilowatt-Hours (kWh) for the Year 2024

Month	Mexico	Sta. Ana	Total
January	8,159,174	2,892,259	11,051,433
February	9,000,510	2,858,735	11,859,245
March	8,691,542	2,931,086	11,622,628
April	10,409,075	4,017,105	14,426,180
May	11,409,442	4,482,759	15,892,201
June	11,318,559	4,006,515	15,325,074
July	9,780,792	3,571,084	13,351,876
August	8,911,488	3,713,836	12,625,324
September	8,776,926	3,439,409	12,216,335
October	10,025,816	3,544,173	13,569,989
November	10,080,805	3,548,953	13,629,758
December	9,588,752	3,347,025	12,935,777
		Total	158,505,820

Table 3. Kilowatt-Hour (kWh) Electricity Rates for the Year 2024

Month	KWH Rate
January	9.87
February	9.51
March	8.49
April	6.82
May	9.49
June	8.04
July	9.85
August	10.79
September	11.39
October	9.83
November	9.87
December	9.82
Average	9.48

4.1.1. System Loss for defective kWh meters before and after Recovery Preventive Maintenance (RPM)

Table 4 contains the summary of the total system loss of the breakdown issues of defective kWh meters after using recovery preventive maintenance. See equation number 1 for detailed calculation. Table 5 shows the summary of the calculation of the total system loss of the breakdown issues of defective meters before using recovery preventive maintenance by assuming a value of 10% total system loss reduced from Case I. See equation number 2 for detailed calculation. The Department of Energy's (DOE) System Loss Reduction Program emphasizes key technical measures such as testing and calibration of kWh meters, system load balancing, and thermal scanning, aiming to reduce system losses to at least 9.5% for public utilities and 14% for rural electric cooperatives over a defined period Department of Energy (2020) [12].

Table 4. Summary of Total system loss of defective meters after using Recovery Preventive Maintenance (Case I)

Reason	Total System Loss in kWh	Total System Loss in %
Change Meters	805	0.00051
Stop Meters	20957	0.01322
Low Consumption	8078	0.00510
Reverse Meters	909	0.00057
Defective Display	642	0.00041
Low Voltage	173	0.00011
Neutral Problem	453	0.00029
Defective/Occupant	103	0.00006
Melted	273	0.00017
Total:	32393	0.02044

Table 5. Summary of Total System Loss of Defective Meters before Using Recovery Preventive Maintenance Case II (Assume that the Total System Loss Reduced of Case I is by 10%)

Reason	Total System Loss in kWh	Total System Loss in %
Change Meters	894	0.00056
Stop Meters	23286	0.01469
Low Consumption	8976	0.00566
Reverse Meters	1010	0.00064
Defective Display	713	0.00045
Low Voltage	192	0.00012
Neutral Problem	503	0.00032
Defective/Occupant	114	0.00007
Melted	303	0.00019
Total:	35992	0.02271

4.1.2. Computation of Total System Loss Reduced from (Case I) and (Case II)

Table 6 contains the summary of the computation of system loss kWh and system loss % reduced from case I and case II. See equation number 3 for detailed calculation. Table 7 shows the summary of the total energy that can be saved from case I and case II. Table 8 presents the total computed annual savings in Php. See equation number 4 for detailed calculation.

Table 6. Summary of Total System Loss Reduced from (Case I) and (Case II)

System Loss kWh			Total System Loss
Case II	System Loss kWh Case I	Total System Loss Reduce kWh	Reduce %
35992	32,393	3,599	10

Table 7. Summary of the Total Energy Saved in kWh from Case I and Case II

System Loss kWh Case II	System Loss kWh Case I	Energy Saved kWh
35,992	32,393	3,599

Table 8. Summary of the Total Annual Savings in PHP

Energy Saved kWh	Annual Savings (PHP)
3,599	34,118.52

As shown in table 10, it is the summary of Return of Investment and Cost Benefit from Case I and Case II. See equation number 5 for the ROI and equation number 6 and 7 for Cost Benefit for detailed calculation.

Table 9. Summary of ROI and Cost Benefit of Case I

Case	ROI (YEARS)	Cost Benefit
I & II	6	1.16

Based on a thorough analysis of the collected quantitative records and qualitative data, the significant findings are as follows:

Considering the result obtained from this study utilizing the RPM, Case I shows significant impact on the reduction of Non-Technical Losses in PELCO 1. The table below shows the summary of analysis results.

Table 10. Summary of Findings

Criterion	Values	Unit
System Loss kWh of Case I	32,393	kWh
System Loss kWh of Case II	35,992	kWh
System Loss % of Case I	0.02044%	%
System Loss % of Case II	0.02271%	%
Total System Loss Reduced kWh	3,599	kWh

Energy Saved kWh of Case I	3,599	kWh
Peso Savings of Case I	34,118.52	PHP
ROI	6	year
CBA	1.16	PHP

4.2. Qualitative Interpretation

This section describes the thematic analysis performed on qualitative data gathered through semi-structured interviews with Mexico, Sta. Ana branch personnel of PELCO I. The answers were coded and placed in general themes that are relevant to the main research question using systematic coding and categorization. These qualitative findings are to cross-validate with technical data to enhance the interpretation of the reduction of system loss and determine the effectiveness of the Recovery Preventive Maintenance (RPM). Table 11 provides an overview of the six individuals who participated in the interview process.

Table 11. Respondents

Qty.	Designation	Department
2	Preventive Maintenance Crew	Mexico, Sta. Ana Office
2	Meter Readers	Mexico, Sta. Ana Office
1	Technical Personnel in Data Control of kWh Meters	Mexico, Sta. Ana Office
1	Technical Personnel in Field	Mexico, Sta. Ana Office

PELCO I maintenance crews rely on field report-driven reactive maintenance. Conducting routine checks by comparing meter readings and visually inspecting physical components, especially in cases where readings have not changed is a sign of stop meter issues. Key issues are meter bases burned due to overloading and dangers from live wires. Despite the challenges, adherence to ISO procedures and improved meter clustering has enhanced meter safety and reliability.

Meter readers are the primary respondents to detect faulty meters. They tag the faulty meters and perform initial troubleshooting activities. Accurate reading and early reporting are essential in reducing billing errors and non-technical system losses.

Technical staff recognized a number of issues including faulty readings from outdated electromechanical meters, faulty cables, and the poor preventive maintenance schedules. The use of digital and smart meters, as well as improved training and installation practices, can reduce system losses to a large degree.

5. Conclusion

This study presents the conclusions along with the main findings drawn from the analysis in the study. The purpose is to highlight the main lessons learnt from the research.

The findings of the research support the following conclusions in both quantitative records and qualitative data:

- The system loss reduced in terms of kWh was highly noticeable from 35,992 in Case II it decreased to 32,393 in Case I. Therefore, the system loss reduction in terms of kWh was 3,599 after utilizing the RPM.

- It can save annual energy of 3,599 kWh.
- It can increase the annual revenue of PELCO I by 34,118.52 Php.
- Return of Investment can be gained in a span of 6 years.
- Every peso spent on RPM, the utility recovers 1.16 Php.
- Staff consistently mentioned that major losses in the system were attributed to technical faults such as loose terminal screws, degraded wiring, and bypassed connections issues directly addressed by Recovery Preventive Maintenance (RPM).
- Inaccurate manual meter reading was cited as another major source of error, thereby necessitating the transition to digital meters for proper billing accuracy and reliability.
- Respondents stressed that before the advent of RPM, maintenance activities were mainly reactive, initiated only when complaints or obvious faults arose. With the introduction of a more structured and proactive approach, fewer customer complaints and better meter performance were observed by field personnel.
- Moreover, the staff favored clustering of meters as being one appropriate measure for ensuring safety, facilitating inspection, and decreasing maintenance time.

In short, the quantitative and qualitative findings affirm that RPM is effective not only in reducing system loss but also plays a vital role in enhancing field operations, operational safety, and service reliability. Thereby confirming the very insightful contribution of the people involved in meter servicing and monitoring whose practical experience and commitment are instrumental to the success of preventive maintenance initiatives.

6. Recommendations

Based on the findings and conclusions of this study, the following recommendations are given:

1. PELCO I must expand the classification of faulty meters to include additional potential causes, in addition to the current reasons of "stop meter," "low consumption," and "reverse meter." The current classifications are helpful but may not entirely reflect the vast array of technical or operational malfunctions that account for system loss.
2. The study focuses solely on Mexico–Sta. Ana branch of PELCO I. In the interest of generalizing the findings, the paper should then recommend for future research that more branches or service areas be included. A substantial dataset would allow more statistical representation and assist in determining whether RPM performs uniformly under different geographical and operational settings.
3. A more detailed cost-benefit analysis would strengthen the study by providing a more informative and in-depth in its financial analysis. Although the present form does give ROI and annual savings figures, it would be improved by breaking down costs into singular constituents like the unit price for meters, labor costs, materials used, and administrative overhead. Being more detailed, it would make it easier for readers to grasp the amount of total investment needed. In addition, including a sensitivity analysis that considers changing electricity prices would make the economic analysis more informative by showing how changes in energy prices would affect total savings and rate of return on investment.

4. To strengthen the reliability of the study, future researchers are encouraged to collect and analyse actual or real-time data rather than relying solely on assumptions. While assumptions provide a useful starting point, gathering empirical data would offer stronger evidence to support the conclusions and further validate the effectiveness of the RPM program. This approach would also enhance the study's credibility and applicability in real-world settings.

Declarations

Source of Funding

The authors received no specific funding for this work.

Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

All listed authors have contributed sufficiently to the work to be included as co-authors.

Informed Consent

All participants in this study voluntarily gave their informed consent prior to their involvement in the research.

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